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PROPOSED TESTS OF CPT SYMMETRY USING D MESONS

DON COLLADAY and V. ALAN KOSTELECKÝ
Indiana University, Physics Department, Bloomington, IN 47401, USA

Parameters describing CPT violation are extracted from a variety of rate asymmetries in the neutral-D system. The precision to which these parameters could be measured in present and planned machines is examined.

CPT symmetry is known to be preserved by local, relativistic, point-particle field theories.[1] This symmetry has been experimentally verified to a high degree of accuracy using the neutral-kaon system.[2] The precision attained in such experiments makes CPT an excellent probe of fundamental particle physics. Additional motivation to search for CPT violation comes from a proposed mechanism through which string theory might lead to violations of CPT at a level comparable to recent experimental bounds.[3,4]

The interferometric nature of the K system that makes sensitive CPT tests possible is shared by both the D and B systems.[4−6] In this talk, some prospects for using the D system for CPT tests are briefly described. Further details and our notational conventions can be found in ref. 6.

The D system might naively be viewed as less useful for CPT studies due to the small expected size of the mixing parameter x characterizing the decay time relative to the mixing time. However, the suppression by x of the complex parameter δ_D describing indirect D-system violation can be an advantage in isolating other quantities,[6] including parameters for direct D-system CPT violation and the parameter δ_K for indirect K-system CPT violation. The K-system dependence arises when D decays into neutral kaons are studied.

Two types of experiment are considered: one involving decays of uncorrelated D mesons, and the other involving the production of $\psi(3770)$ with subsequent decay into correlated neutral-D pairs. The variables of experimental interest are asymmetries in decay rates, which have been classified.[6]

An example of an asymmetry isolating δ_D can be constructed from the rates of double-semileptonic decays of correlated D mesons to a final state f in one channel and its charge conjugate $\overline{f}$ in the other:

$$A_{f,\overline{f}} \equiv \frac{\Gamma^+(f,\overline{f}) - \Gamma^-(f,\overline{f})}{\Gamma^+(f,\overline{f}) + \Gamma^-(f,\overline{f})} \simeq x(\mathrm{Re}\,\delta_D + 2\mathrm{Im}\,\delta_D) \quad . \tag{1}$$

The superscripts + and − on the decay rates Γ indicate that the decay into f occurs, respectively, before and after the decay into $\overline{f}$. Note the suppression of δ_D by the factor x.

To obtain an example of an asymmetry involving δ_K for kaons, consider the following combination of total decay rates R_S of uncorrelated D^0 mesons into final states containing K_S and $\overline{R}_S$ of $\overline{D^0}$ mesons into the same final states:

$$A_S \equiv \frac{\overline{R}_S - R_S}{\overline{R}_S + R_S} \quad . \tag{2}$$

The difference between this asymmetry and an analogous one involving K_L final states is

$$\begin{aligned} A_L - A_S \quad = \quad & -4\mathrm{Re}\,\delta_K + 2\mathrm{Re}\,(\overline{x}_K - x_K) + 2x\mathrm{Re}\,(\epsilon_D - \epsilon_K - y_K) \\ & +4x\left[\mathrm{Im}\,(\epsilon_K + \epsilon_D) + \frac{\mathrm{Im}\,F_K}{\mathrm{Re}\,F_K}\right] \\ & +4x^2\mathrm{Re}\,(\delta_D + \delta_K - \tfrac{1}{2}(\overline{x}_K - x_K)) \\ & -2x^2\mathrm{Im}\,(\delta_D - \delta_K + \tfrac{1}{2}(\overline{x}_K - x_K)) \quad . \end{aligned} \tag{3}$$

The various quantities in this equation parametrize direct and indirect T and CPT violation in the D and K systems. Applying the condition $x \ll 1$ of small D-system mixing suppresses all but the first two terms, thereby specifically isolating CPT-violating parameters in the K system. The first term, $-4\mathrm{Re}\,\delta_K$, parameterizes indirect CPT violation in the K system. The second term, $2\mathrm{Re}\,(\overline{x}_K - x_K)$, is a measure of simultaneous direct CPT breaking and violation of the $\Delta C = \Delta Q$ rule.

Given an expression for an asymmetry depending on some parameter, the number of events needed to measure that parameter to within one standard deviation σ can be estimated directly if experimental acceptances and backgrounds are neglected.[7] Consider first Eq. 1. The number $N_{\psi(3770)}$ of $\psi(3770)$ events required is determined using the inverse branching ratios of the $\psi(3770)$ into the relevant double-semileptonic final states and summing contributions to the asymmetry. This gives

$$N_{\psi(3770)}(\mathrm{Re}\,\delta_D + 2\mathrm{Im}\,\delta_D) \simeq \frac{9}{x^2\sigma^2} \simeq \frac{3600}{\sigma^2} \quad . \tag{4}$$

The numerator 3600 assumes $x \simeq 0.05$, which is close to the experimental limit and illustrates the best possible scenario for bounding δ_D. The value of x may theoretically be this large if long-distance dispersive effects dominate[8] or if certain extensions of the standard model are invoked.[9]

Next, an estimate is made of the accuracy that can be achieved in the measurement of the parameters in Eq. 3. The inverse branching ratio of the D meson into the relevant final state, which is typically of the order of several percent, is needed as input. The number N_D of uncorrelated D mesons required to measure $\mathrm{Re}\,\delta_K$ to an accuracy of one standard deviation σ is

$$N_D(\mathrm{Re}\,\delta_K) \simeq \frac{1}{16\sigma^2 \mathrm{BR}(D^0 \to \overline{K^0} + any)} \quad . \tag{5}$$

For simplicity, any violations of the $\Delta C = \Delta Q$ rule have been assumed to be independent of direct CPT violation.

Prospects for experimentally studying CPT symmetry using the neutral-D system have been presented. For a sample of 10^8 $\psi(3770)$ events, which could be generated by a τ-charm factory, a theoretical bound could be placed on indirect D-system CPT violation at about the 10^{-2} level if x is large enough. Furthermore, the small size of x can be used to advantage in extracting the parameter δ_K for indirect CPT violation in the K system. Its real part could in principle already be bounded to the 10^{-2} level or better using the currently available 10^5 reconstructed neutral-D events and could be significantly improved in the near future. This provides a different method of measuring δ_K. We remark that it is also possible to extract certain parameters for direct CPT violation in the D system using similar methods.[6]

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